

Citation for published version:

Dhokia, V, Nassehi, A, Wolf, SA & Newman, ST 2013, 'Cryogenic CNC machining of individualised packaging', Paper presented at 37th International MATADOR 2012 Conference, Manchester, UK United Kingdom, 25/07/12 - 27/07/12 pp. 165-168.

Publication date:

2013

Document Version

Early version, also known as pre-print

[Link to publication](#)

University of Bath

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Cryogenic CNC Machining of Individualised Packaging

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Abstract. With the continuing growth in the high value product manufacturing sector there is a need to provide new ways to store and transport high value precision parts without damage and contamination. Traditional packaging is produced from foams and elastomers using forming techniques. This provides difficulty for producing individualised packaging solutions as individual moulds and forming tools would be required. In addition present solutions do not provide adequate packaging as they can cause damage to the part in some cases. This paper explores the design and manufacture of precision machined individualised neoprene foam packaging using cryogenic CNC machining technology. Cryogenic CNC machining is discussed and an example case study is presented showing the viability and efficacy of the proposed design and manufacturing method.

Keywords: Cryogenic, CNC, Packaging

1 Introduction

Packaging is a major issue for a variety of different industrial and consumer based products. The fundamental aim is to prevent damage and part contamination during storage and transportation. Current methods primarily consist of forming technologies such as thermoforming to produce the required geometrically accurate packaging. For lower value products, simple, cut to fit foam inserts, polystyrene, and bubble wrap packaging is used and this can in a number of cases prove to be inadequate. Producing specific packaging using current methods is difficult as individual moulds are required, which subsequently leads to increased cost and manufacturing process chain. Fig. 1.1 shows an example of a soft foam package.



Fig. 1.1. Soft material packaging example for mass produced parts

Correct packaging is vital, particularly if parts are being sent to customers as replacement or as a consignment of 'bits' for onsite assembly. It is also useful when parts need to be transported for further processing. In addition, as these types of parts are often expensive, packaging takes on added significance, not only for product security against damage, but also from a business perspective. A well-packaged part is likely to procure added enhancement to the product, thus increasing its customer appeal and value. For example, perfume packaging can represent 22% of the manufacturer's gross costs and can contribute up to 40% of the value of the product [1]. It is not merely the case that a product or part should be stored or transported in adequate standardised packaging, particular if the part being packaged is of high value.

A process being pioneered at the University of Bath is that of direct cryogenic CNC machining of soft polymers [2, 3]. Using this process it becomes possible to produce product specific packaging that can be directly machined from different materials depending on the end application and on the amount of part protection required. This paper illustrates the concept through a case study for design and manufacture of individualized packaging for specialist bicycle parts.

2 Cryogenic CNC Machining of Elastomers

The concept of soft elastomeric material machining is based on the need to remove the moulding process, which can be expensive and does not allow for constant design change and inhibits customised and individualised design [4, 5]. Direct CNC machining of polymers provides the ability to change designs instantaneously emphasizing the realistic opportunity to produce individualised product packaging. However the major challenge of machining polymers and soft elastomeric materials is the inability to conventionally impart a sufficient chip bending moment, which can result in significant deformation, tearing and

burning of the material. Fig. 1.2 presents example images of different machining conditions for soft materials. The first image is captured from dry machining and it is clear to see the tearing and serration marks imparted on the material. The second image illustrates a chip sample from cryogenic machining of neoprene foam and it is clear to see the clean-cut edges and full chip formation, indicating a significantly improved machined part and surface.

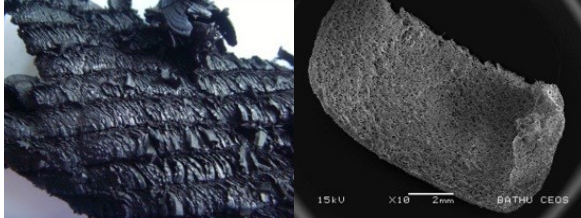


Fig. 1.2. Surface from dry machined rubber and a fully formed chip from cryogenically machined neoprene.

The cryogenic CNC machining facility [2] has been designed to machine a range of soft elastomer materials, which include, neoprene foam and ethylene vinyl acetate (EVA). The major aim of the cryogenic CNC machining process is to freeze a soft material to below its glass transition temperature (T_g) value and then to directly machine it using standard conventional CNC machine tools and tooling. The T_g is the temperature at which a material shows similarities to that of a glass type structure. Only after this temperature has been achieved and is maintained can the material be successfully machined. Each material has its own T_g value, which is determined using dynamic mechanical thermal analysis methods (DMTA) [6]. Machining above this temperature can lead to deformed features and material tearing as illustrated in fig.1.2. leading to inferior parts, products and potentially reduced tool life.

The cryogenic CNC machining facility consists of a cryogenic fixture designed to securely clamp a test part sample, an 18mm diameter vacuum jacketed piping that feeds directly from a 180-litre high pressure Dewar into a custom designed fixture and a multi nozzle spray jet unit. The temperature of the fixture is monitored using a series of low temperature thermal probes. The material block is securely located inside the fixture and is cooled directly using liquid nitrogen (LN_2), with the use of the spray jet unit. The spray jet unit activates using a timer mechanism, so as to regulate the amount of LN_2 used during a given machining cycle. Fig. 1.3 provides a schematic of the cryogenic machining setup.

The developed cryogenic CNC machining facility is designed to be retrofitted to any type of vertical machining centre. The control unit for controlling the rate of flow of LN_2 at any given time in the machining process is totally independent of the machine tool and was developed as part of another study [4]. This is a timer-based system that uses the time taken to achieve the

material specific T_g and the time taken to maintain this T_g as the input factors.

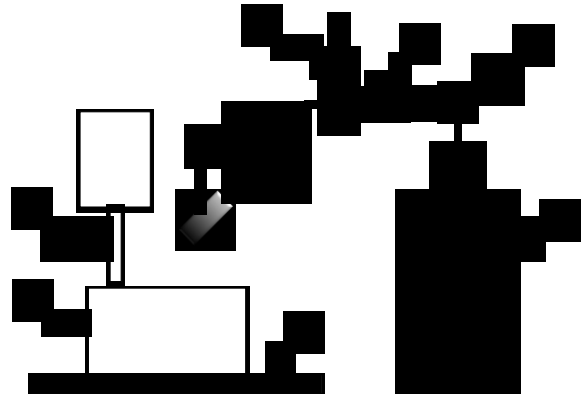


Fig. 1.3. Schematic setup for cryogenic machining, 1-Liquid nitrogen Dewar, 2- pressure gauge, 3- gate valve, 4- solenoid on/off valve, 5- specially designed nozzle, 6- cutting tool, 7- workpiece, 8- machine table

3. Individualised packaging design

There are different types of packaging solutions that can be used depending on the part / product required to be packaged, transported and or stored. Mass produced products typically tend to use thermoformed packaging manufactured using specifically designed mould tools and soft low-density, impact attenuating materials. The following fig. 1.4 illustrates an example of the current method for mass produced packaging.

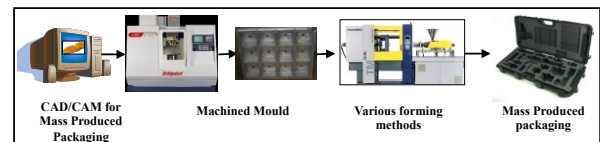


Fig. 1.4. Mass produced packaging

The design of individualised packaging requires a totally new approach. In order to produce the correct packaging geometry a CAD representation of the part is required. This can be either obtained from the CAD part file or from using scanning reverse engineering techniques to produce an accurate 3D digital representation of the part features and geometry. Using the CAD part, fully individual male type negative moulds of the part can be replicated. In addition, these computer-generated designs can then be altered, adjusted and manipulated to increase packaging support for the part and part numbers corresponding to the part can be engraved directly into the material.

Using the generated packaging design moulds CAM techniques can be used to generate the machine specific CNC code. The Cryogenic CNC machining process can

then be used to freeze the material and machine the required packaging from a variety of different soft materials, which depend on the end application and on the amount of material support required for the part.

4 Methodology

The methodology for designing and manufacturing of a fully individual product packaging solution consists of using scanning technology to capture the part geometrical information and then using the developed cryogenic CNC machining technology to produce the required packaging. The methodology used for the individualised packaging is shown in fig. 1.5 through an IDEF0 representation. The three main areas for producing a fully individualized soft material package consist of scanning, designing and CNC machining. The scanning output is a point cloud of the part data, which can be meshed together. The output of the design phase is the mould packaging design and the output from the third phase is the individualised packaging solution.

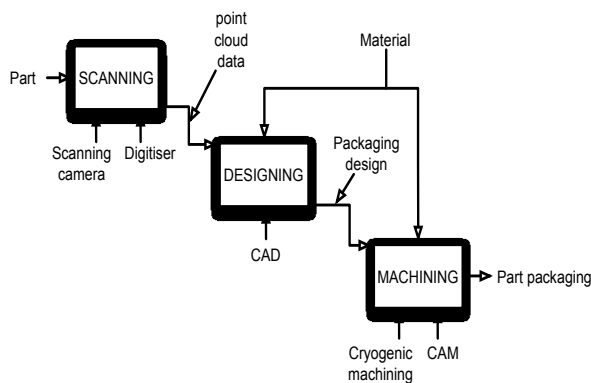


Fig.1.5. IDEF0 representation of the methodology

4.1. Case study and results

In order to demonstrate the efficacy of the developed cryogenic CNC machining process and the individualised packaging design a case study example was developed and tested for a high value product.

Moulten Bicycles based in the UK are a company that specialize in hand made custom bicycles retailing in the price range of £9000 to £14000 [7]. A handle bar holder was chosen as the case study example, as this part requires safe damage free transportation around the production site for different manufacturing and finishing operations. In addition, this part is often sent to the customer directly as part of a consignment of bits to be assembled by the customer or as a replacement part. Fig. 1.6 illustrates an example of the bicycle and handle bar holder that is used as the case study example.

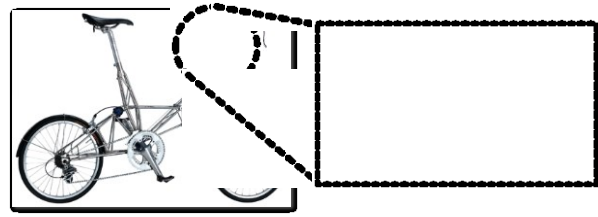


Fig. 1.6. The Moulten bicycle and the case study part

The process for designing of the product specific packaging first begins with capturing of the part data digitally. The handle bar holder is scanned using a 3D laser-stripe non-contact scanner to capture the complete geometry of the part in the form of a digitised point cloud. The part requires two scans, which are then meshed together. The density of the point cloud is controlled so as not to capture large amounts of redundant points, which would increase the processing and design time. The orientation of the part throughout the scanning process is critical in order to capture all the necessary data. Anomalous data, captured from the scanning, such as background points can be filtered out and removed in the design process. The point cloud data is converted into curves and surfaces and this provides a functional CAD model with which to design the part packaging around. Fig. 1.7 shows the scanned part and the final CAD model of the part.

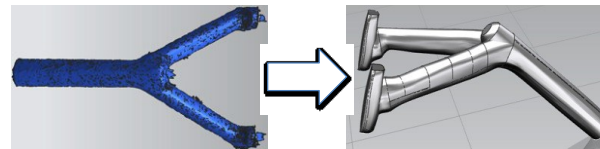


Fig. 1.7. Digitised part and full CAD part

The part packaging solution is then designed and in this case a sandwich type configuration is used in order to encapsulate the part in the central sections. This provides full part protection. For this particular case study the part is located centrally so as the degree of impact resistance is consistent around the part. Also, as the part has two additional assembly items, these are positioned within the complete handle bar holder packaging solution. Figure 1.8 illustrates an example of the designed packaging.

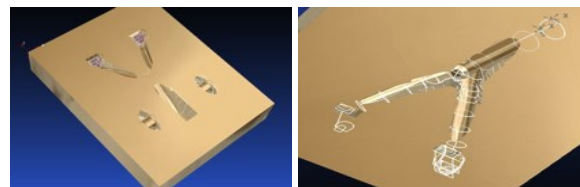


Fig. 1.8. The CAD packaging design

Using the cryogenic CNC machining facility and the correct material dependent machining parameters each

segment of the package is machined. Tooling is selected based on the geometry, required feature size and generated process plans. The machining strategies are also devised based on the material properties and the complexity of the part.

Figure 1.9 depicts the finished neoprene foam packaging solution for the Moulten Bicycle handle bar.



Fig. 1.9. The final machine packaging

5 Conclusions

This paper has illustrated and demonstrated a totally new process for rapidly machining elastomeric material on conventional CNC machine tools using liquid nitrogen freezing technology. The concept of individualised packaging is discussed and an example case study is presented and machined using the cryogenic CNC machining process. Using this type of design and manufacturing process it makes it increasingly cost effective and efficient to produce high quality precision machined packaging for bespoke and high value products and parts.

6 References

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